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An investigation of the attenuation provided by the Surefire EP3 Sonic Defender™ earplug

Sharon M. Abel

Ann Nakashima

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Principal Author

Original signed by Sharon M. Abel, PhD

Sharon M. Abel, PhD

Defence Scientist, Individual Readiness Section

Approved by

Original signed by Pang Shek, PhD

Pang Shek, PhD

Head, Individual Readiness Section

Approved for release by

Original signed by K. C. Wulterkens

K. C. Wulterkens

for Chair, Document Review and Library Committee

Abstract

The sound attenuation provided by the Surefire EP3 Sonic Defender™ earplug was determined in five males and five females. According to the manufacturer, an orifice in the plug allows safe sound levels to pass while lowering potentially harmful levels above 80 dBA from impulse noise by 35 dB. With the orifice closed the device performs like a conventional level-independent earplug. In each subject, hearing thresholds were measured at nine one-third octave noise band centre frequencies with the ears unoccluded and fitted with the Surefire EP3 with the orifice open and closed. Attenuation was defined as the difference between the protected and occluded thresholds. With the orifice closed attenuation increased non-monotonically from 14.5-31.0 dB from 0.125 kHz to 8 kHz. A decrease to 19.1 dB was evident at 4 kHz. With the orifice open attenuation increased from 4.4-27.0 dB with a decrease to 16.6 dB at 4 kHz and 6.3 kHz. The greatest differences due to mode of operation (9-10 dB) were observed at 0.125 and 0.25 kHz. There was no effect of gender of subjects. Comparison with the E-A-R® Combat Arms earplug, which also has modes of operation for continuous and impulse noise indicated that the two devices were similar for the orifice open condition. For the orifice closed condition the Combat Arms earplug provided attenuation of 20.7-40.3 dB, on average 8 dB more than the Surefire EP3. Surefire EP3 attenuation was also compared with insertion loss measurements obtained using an acoustic test fixture. Insertion loss overestimated attenuation by approximately 16 dB in the range of 1 kHz to 6.3 kHz, regardless of mode of operation.

Résumé

Nous avons déterminé l'atténuation du son fournie par le bouchon d'oreille EP3 Sonic Defender^MC de Surefire chez cinq hommes et cinq femmes. Selon le fabricant, un orifice percé dans le bouchon permet aux sons dont le niveau est sans danger de passer tout en réduisant de 35 dB les bruits impulsifs dont le niveau est dangereux (plus de 80 dBA). Lorsque l'orifice est fermé, le bouchon se comporte comme un bouchon classique dont l'atténuation ne varie pas selon le niveau sonore. Le seuil d'audibilité de chaque sujet a été mesuré à l'aide de 9 fréquences centrales de bandes de bruits d'un tiers d'octave. Les essais ont été réalisés sans les bouchons et avec les bouchons (orifice ouvert et fermé). L'atténuation se définit comme la différence entre le seuil mesuré avec le dispositif et celui obtenu sans le dispositif. Avec l'orifice fermé, l'atténuation augmente de façon non monotone, entre 0,125 kHz et 8 kHz, de 14,5 à 31 dB. Une diminution à 19,1 dB se manifeste à 4 kHz. Avec l'orifice ouvert, l'atténuation augmente de 4,4 à 27,0 dB avec une diminution à 16,6 dB à 4 kHz et 6,3 kHz. Les différences les plus marquées entre les modes d'utilisation (entre 9 et 10 dB) s'observent à 0,125 et 0,25 kHz. Le sexe des sujets est sans effet. La comparaison avec le bouchon Combat Arms de E-A-R®, qui a lui aussi un mode d'utilisation pour les bruits continus et un autre pour les bruits impulsifs, indique que les deux dispositifs sont similaires lorsqu'utilisés en mode orifice ouvert. Lorsque l'orifice est fermé, le bouchon Combat Arms fournit une atténuation de 20,7 à 40,3 dB, soit 8 dB de plus que l'EP3 de Surefire en moyenne. L'atténuation de l'EP3 a également été comparée avec des mesures de perte d'insertion obtenue à l'aide d'un appareil d'essai acoustique. Cette méthode de mesure surestime l'atténuation par environ 16 dB dans la gamme allant de 1 kHz à 6,3 kHz, peu importe le mode d'utilisation.

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Executive summary

An investigation of the attenuation provided by the Surefire EP3 Sonic Defender™ earplug

Sharon M. Abel; Ann Nakashima; DRDC Toronto TR 2008-040; Defence R&D Canada – Toronto; May 2008.

Introduction: Personal hearing protection devices (HPDs) are an effective means of controlling the level of sound reaching the ear. The present study was a laboratory assessment of the Surefire EP3 Sonic Ear Defender™ earplug. This device is made of a soft hypoallergenic medical grade polymer. It is comprised of two parts: a ring to secure the device in the bowl of the outer ear and a plug that is inserted into the ear canal. According to the manufacturer an orifice at the tip of the plug allows sound levels that are safe for hearing to pass while lowering harmful levels above 80 dBA from impulse noise by about 35 dB. When the orifice is closed, the device operates as a conventional passive level-independent hearing protector. Attenuation increases with stimulus frequency. The objective of the present study was to measure the attenuation that would be provided by this device in both the orifice open and closed modes of operation, in the absence of an impulsive sound. Five males and five females participated. In each, hearing thresholds were measured at nine one-third octave noise band centre frequencies with the ears unoccluded and protected. Attenuation was defined as the difference between the protected and unoccluded hearing thresholds.

Results: The mean attenuation of the Surefire EP3 with the orifice closed increased non-monotonically from 14.5-31.0 dB as the stimulus frequency increased from 0.125 to 8 kHz. The attenuation at 4 kHz, the most susceptible frequency for noise-induced hearing loss, was 19.1 dB. With the orifice open, attenuation increased from 4.4-27.0 dB, with a decrease to 16.6 dB at 4 kHz and 6.3 kHz. Greatest differences due to mode of operation (9-10 dB) were observed at 0.125 and 0.25 kHz. Gender of subjects was not a significant factor. These outcomes were compared with results previously obtained for the E-A-R® Combat Arms earplug which also has modes of operation for continuous and impulse noise. The Combat Arms plug is currently used in U.S. military operations. For the impulse noise mode of operation the conventional attenuation of the two devices was similar. For the continuous noise mode of operation, the Combat Arms plug provided 20.7-40.3 dB of attenuation, with 34.3 dB at 4 kHz. Averaged across frequencies the difference between the devices was 8 dB. At 4 kHz and 6.3 kHz the difference was 15 dB. The results were also compared with insertion loss measurements made using an acoustic test fixture (ATF). The latter proved to be a poor model of human performance, overestimating the attenuation by 16 dB on average from 1 kHz to 6.3 kHz, for the two modes of operation.

Significance and Future Plans: Determination of the degree to which the Surefire EP3 would attenuate impulse noise was beyond the scope of the present study. In the case of continuous noise, the results indicated that with the orifice open this device would not interfere with speech understanding. In the closed mode of operation, the attenuation was less than achieved with the E-A-R® Combat Arms earplug in current usage. Choice of device might be determined by ease of fitting and comfort. Field trials are in progress to determine acceptability by military personnel.

Sommaire

An investigation of the attenuation provided by the Surefire EP3 Sonic Defender™ earplug

Sharon M. Abel; Ann Nakashima; DRDC Toronto TR 2008-040; R & D pour la défense Canada – Toronto; Mai 2008.

Introduction : Les dispositifs personnels de protection de l'ouïe sont un moyen efficace de réduire le niveau sonore qui atteint l'oreille. La présente étude est une évaluation en laboratoire du bouchon d'oreille EP3 Sonic Defender^{MC} de Surefire. Ce dispositif est fait d'un polymère souple et hypoallergénique de qualité médicale. Il se compose de deux parties : un anneau pour retenir le dispositif dans la conque de l'oreille externe et un bouchon qui est inséré dans le conduit auditif. Selon le fabricant, un orifice percé dans le bouchon permet aux sons dont le niveau est sécuritaire de passer tout en atténuant d'environ 35 dB les bruits impulsifs dont le niveau est dangereux (plus de 80 dBA). Quand l'orifice est fermé, le dispositif agit comme un dispositif passif classique dont le degré de protection de l'ouïe est indépendant du niveau sonore. L'atténuation augmente avec la fréquence du stimulus. L'objectif de la présente étude est de mesurer l'atténuation fournie par ce dispositif avec l'orifice ouvert et fermé en l'absence de bruits impulsifs. Cinq hommes et cinq femmes y ont participé. Le seuil d'audibilité de chaque sujet a été mesuré sans le dispositif et avec le dispositif à l'aide de 9 fréquences centrales de bandes de bruits d'un tiers d'octave, sans les bouchons et avec les bouchons. L'atténuation se définit comme la différence entre le seuil mesuré avec le dispositif et celui obtenu sans le dispositif.

Résultats : L'atténuation moyenne de l'EP3 avec l'orifice fermé augmente de façon non monotone de 14,5 à 31,0 dB quand la fréquence du stimulus passe de 0,125 à 8 kHz. À 4 kHz, la fréquence la plus susceptible de causer une perte d'ouïe due au bruit, l'atténuation est de 19,1 dB. Avec l'orifice ouvert, l'atténuation augmente de 4,4 à 27,0 dB, avec une diminution à 16,6 dB à 4 kHz et à 6,3 kHz. Les plus grandes différences dues au mode d'utilisation (entre 9 et 10 dB) s'observent à 0,125 et 0,25 kHz. Le sexe des sujets n'était pas un facteur significatif. Ces résultats ont été comparés à ceux obtenus précédemment pour le bouchon d'oreille Combat Arms de E-A-R®, qui a lui aussi un mode d'utilisation pour le bruit continu et un autre pour le bruit impulsif. Ce bouchon est actuellement utilisé dans des opérations militaires américaines. Pour le mode de protection contre les bruits impulsifs, l'atténuation des deux dispositifs est semblable. Pour le mode de protection contre les bruits continus, le bouchon Combat Arms fournit entre 20,7 et 40,3 dB d'atténuation, avec 34,3 dB à 4 kHz. En faisant la moyenne pour toutes les fréquences, la différence entre les dispositifs est de 8 dB. À 4 kHz et 6,3 kHz, elle est de 15 dB. Les résultats ont également été comparés à des mesures de perte d'insertion réalisées au moyen d'un appareil d'essai acoustique. Ce dernier s'est avéré être un mauvais modèle de la physiologie humaine : entre 1 kHz et 6,3 kHz, il surestime l'atténuation de 16 dB en moyenne pour les deux modes d'utilisation.

Portée et recherches futures : La détermination du degré d'atténuation des bruits impulsifs par l'EP3 dépasse la portée de la présente étude. Dans le cas du bruit continu, les résultats indiquent que le dispositif n'entrave pas la compréhension de la parole quand son orifice est ouvert. Dans le mode d'utilisation fermé, l'atténuation était moindre que celle obtenue avec le bouchon d'oreille Combat Arms de E-A-R® utilisé actuellement. Le choix d'un dispositif pourrait être déterminé

selon la facilité d’insertion et le confort. Des essais sur le terrain sont en cours pour établir l’acceptabilité par le personnel militaire.

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Table of contents

List of figures

List of tables

Acknowledgements

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1 Introduction

Personal hearing protection devices (HPDs) are an easily implemented and effective means of controlling the level of sound reaching the ear [1]. Utilization helps to minimize the development of noise-induced hearing loss [2]. Conventional earmuffs and earplugs reduce sounds by the same amount, regardless of their level. However, the attenuation achieved is frequency-dependent. Typically, high frequencies are attenuated to a greater degree than low frequencies [3]. Passive level-dependent devices, in contrast, do not impede sounds at low to moderate sound intensities but ensure protection against exposure to high-level impulse noise. One example is the E-A-R® Combat Arms earplug which is now in common usage in military operational environments [4]. This device is comprised of two pre-moulded, flexible plugs made of a thermoplastic elastomer, each with three flanges (see Figure 1). The plugs are attached to each other stem to stem, and are available in one size. Based on the manufacturer's specifications, one of the plugs, labelled the "Indoor" plug, provides conventional sound attenuation of 32.7-43.3 dB from 0.125-8 kHz. The other plug, labelled the "Outdoor" plug, contains a sharp-edged orifice. If the ear receives a shock wave (e.g., a weapon's discharge) turbulence created in the orifice impedes its transmission. Otherwise the sound attenuation ranges from 4.4-22.2 dB. The advantage of the "Outdoor" plug is that in the absence of a weapon's discharge it will interfere only minimally with the perception of speech.

Another passive level-dependent earplug currently being considered for use by the Canadian Forces is the SureFire EP3 Sonic Defender™ (see Figure 2). The device is made of a soft hypoallergenic medical grade polymer and is comprised of a ring to secure the device in the bowl of the outer ear and a plug with two flanges that is inserted into external ear canal. According to the manufacturer, an orifice in the device allows safe levels to pass while lowering potentially harmful levels above 80 dBA by about 35 dB. This is accomplished by means of a patented filter, the Hocks Noise Braker, which converts sonic energy into thermal energy. When the orifice is closed, the device operates as a conventional passive earplug. No data are available on the amount of attenuation that may be achieved with the orifice closed.

The present study was a laboratory assessment of the attenuation achieved with the SureFire EP3 Sonic Defender™ earplug over a broad range of one-third octave noise band frequencies in both open and closed orifice modes of operation. The results were compared with insertion loss data collected using an acoustic test fixture (ATF) that models the human peripheral auditory pathway [5,6]. Since human subjects testing is relatively more time consuming and costly, similarity in outcomes would justify the use of the ATF. The Surefire EP3 data were also compared with attenuation data previously collected for the E-A-R® Combat Arms earplug [4]. In both the present and previous study with the Combat Arms earplug subjects fit the device following verbal instructions. Attenuation values based on subject fits typically fall short of values cited by the manufacturer [1]. It has also been shown that attenuation levels obtained in females may be less than levels obtained in males when the device is available in only one size [7]. This is due to the fact that females generally have smaller ear canals than males, resulting in a poor seal [8]. The SureFire EP3 Sonic Defender™ earplug is available in several sizes. In this study, results for males and females were compared to assess the adequacy of the available sizing.

Figure 1 The E-A-R® Combat Arms earplug.

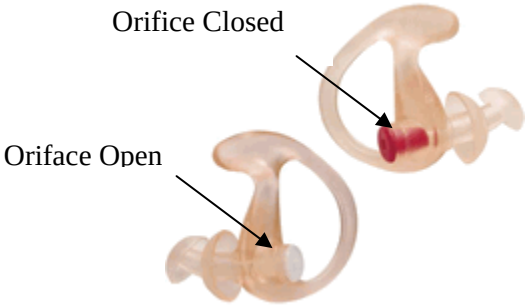

Figure 2 The Surefire EP3 Sonic Defender™ earplug.

2 Methods

2.1 Experimental Design

2.1.1 Human Subjects

Working aged males and females, civilian and military, were eligible to take part. The study protocol was approved in advance by the Defence Research and Development Canada (DRDC) Human Research Ethics Committee. Each subject provided written informed consent before participating. Since achieved attenuation does not interact with hearing status [9], subjects were not screened with respect to pure tone hearing thresholds. In accordance with the American National Standards Institute (ANSI) standard on the real-ear assessment of the attenuation provided by hearing protectors [10], hearing thresholds were measured free-field in each subject for a set of nine one -third octave noise bands with centre frequencies ranging from 0.125 to 8 kHz. Measurements were made with the ears unoccluded (without a hearing protection device) and subsequently with the plug fitted binaurally, first in one and then in the other mode of operation (orifice open and closed), in a quiet background. Order of the two modes was counterbalanced across subjects to equalize possible learning effects. Attenuation was defined as the difference in hearing threshold between the protected and unoccluded values at each frequency, for each of the two modes of operation.

For the occluded conditions, participants were verbally instructed on how to properly insert the earplug in each ear prior to doing so themselves. They were also shown a photograph of the device seated in the external ear. It was explained that there was no danger of self-inflicted injury due to over-insertion. Three sizes (small, medium and large) were available. The experimenter chose one of the three based on visual inspection of the outer ear. Following insertion she checked the fit and in consultation with the subject determined the need to try a second size. This protocol is a variation of Method A (Experimenter-Supervised Fit) described in the ANSI Standard [10].

2.2 Subjects

Five males and five females ranging in age from 26-57 years**,** participated. They were recruited by means of notices sent to all employees of Defence Research and Development Canada – Toronto. Each subject received compensation in accordance with guidelines established at this institution.

2.3 Apparatus

2.3.1 Human Subjects

Subjects were tested individually, while seated at the centre of a double-walled, semi-reverberant, sound proof booth (IAC Series 1200) with inner dimensions 3.5 m (length) by 2.7 m (width) by

2.3 m (height) and ambient noise levels that were less than maximum permissible for audiometric test rooms [11]. A detailed description of the instrumentation and calibration methods have been described previously [12]. A Brüel and Kjaer white noise generator (B&K 1405) and band pass filter (B&K 1617) were used to produce the one-third octave noise band stimuli used in the experiment. The duration and envelope shape of the stimuli were set by means of a Coulbourn Instruments modular system. The output was fed to a manual range attenuator (HP 350-D) and Yamaha power amplifier (RX-V620) and presented free-field over a set of three loudspeakers (Celestion DL10) positioned to create a uniform sound field.

2.3.2 ATF

The ATF is comprised of a standard Knowles Electronics Manikin for Acoustics Research (KEMAR) torso and a specially designed head cast from aluminum-filled epoxy [5,6]. The head includes a mechanical representation of human aural tissues, is covered with artificial skin, has removable pinnae, and weighs 3.3 kg. The KEMAR torso is mounted on a stand, and the head is supported by a compliant neck which models the natural decoupling between the human neck and torso. The ear canals are terminated with DB-100 Zwislocki couplers. An Etymotic ½ inch microphone (ER-11) captured the noise signals at the eardrum, which were analyzed using a Bruel and Kjaer 2133 analyzer. The eardrum microphone has two different settings: flat and diffuse. The flat setting was chosen for these measurements because it models the response of the human ear more accurately. It has been shown that there are no significant differences between the two microphone settings for hearing protector insertion loss [13]. The ATF and its previous versions have been used in previous studies for the evaluation of hearing protection devices in both continuous [13] and impulse [14] noise.

The ATF testing was conducted in the Noise Simulation Facility at DRDC Toronto. The facility is a semi-reverberant room of dimensions 10.55 m (length) by 6.10 m (width) by 3.05 m (height). Noise signals are produced through an array of speakers arranged at one end of the room, which includes eight Equity Sound Investment subwoofers (Model G218s), four Electrovoice Servodrive low range speakers (Model Bass Tech 7) and four Electrovoice Delta Max speakers (Model DMC 1152A). The background noise of the room when the speakers are on is approximately 33 dBA. Pink noise was generated using a Bruel and Kjaer noise generator (Model 1049). The ATF was positioned facing the speaker array at a distance of 3.35 m, 2.35 m from the side wall, with the ears at a height of 1.4 m. It has been shown that resonance effects caused by the room geometry are minimized at this position, thus allowing for the best replication for pink noise [15]. The pink noise was presented at 88 dBA. The spectrum is shown in Figure 3.

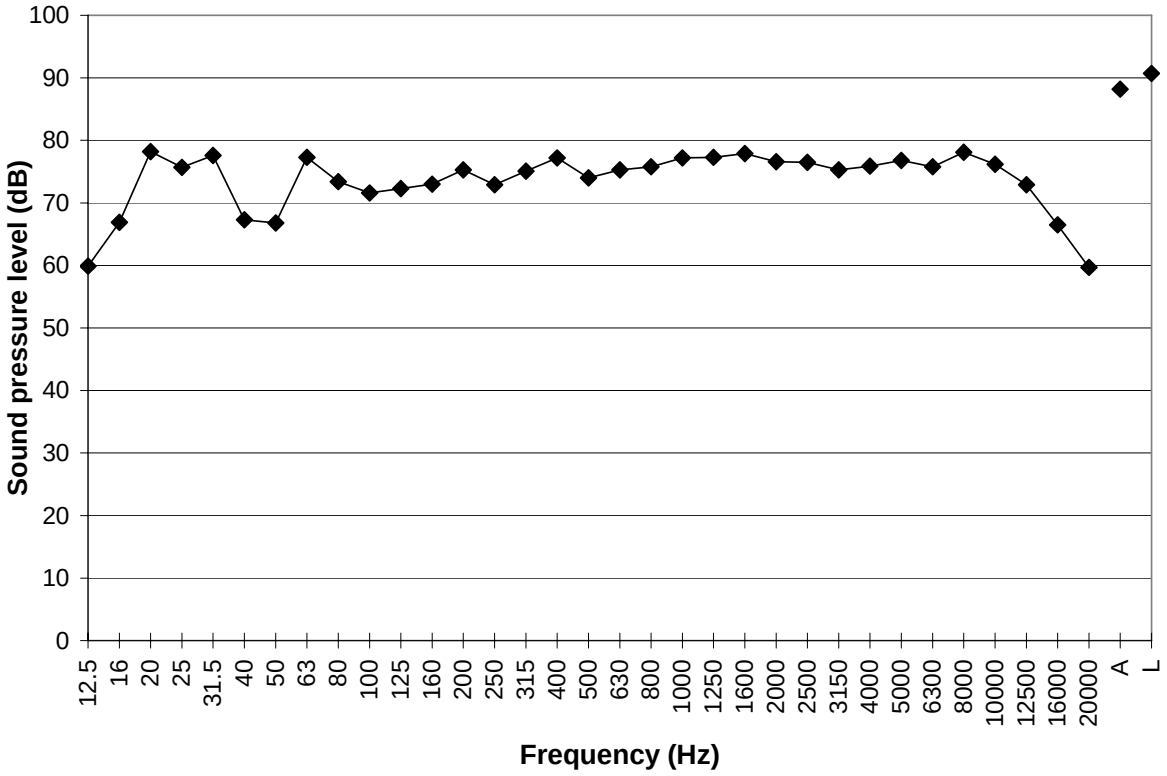

Figure 3 Spectrum of the pink noise used for the ATF measurements.

2.4 Procedure

2.4.1 Human Subjects

Hearing thresholds were measured using a variation of Békésy tracking [16]. The stimulus was a train of short pulses presented over a triad of room speakers. The duration of each pulse was 250 ms including rise and fall times of 50 ms. The time between pulses was 150 ms. Threshold measurements were made once for each of nine one-third octave noise band frequencies, centred at 125, 250, 500, 1000, 2000, 3150, 4000, 6300, 8000 Hz. Participants were given a hand-held pushbutton and asked to press the button as soon as they detected the sound and to keep the button depressed until the sound was no longer audible. The sound level of consecutive pulses increased in steps of 1 dB until the button was depressed and then decreased at the same rate of change until the button was released. The tracking trial was terminated after a minimum of eight alternating intensity excursions with a range of 2 to 20 dB. Hearing threshold was defined as the average sound level of the eight final peaks and valleys.

2.4.2 ATF

All measurements were made with the right ear of the ATF, with the pinna in place. The left ear was blocked with plasticine to reduce any contralateral noise contributions to the measurements. Measurements were made with the right ear unoccluded and subsequently fitted with the Surefire

EP3 Sonic Defender™, with the orifice open and closed. Three consecutive measurements were made for each of the open and closed modes of operation, and the results were averaged. The device was re-fit between trials. The sound levels were recorded at one-third octave bands from 12.5 Hz to 20 kHz. The insertion loss was calculated by subtracting the occluded from the unoccluded levels.

3 Results

3.1 Human Subjects

3.1.1 Sizing of the Device and Comfort

Two males and two females were fit binaurally with the small size, two males and three females were fit with the medium size and one male was fit with the large size of the Surefire EP3 Sonic Defender™. Four of the ten subjects tested found the device to be uncomfortable and one complained of ear pain when the orifice was closed. Two subjects started with the small size and felt discomfort because the device was too deeply seated. Comfort improved when they were fitted with the medium size. One subject snapped off the closure tab when changing the mode of operation with the device fitted. The remaining two subjects felt no discomfort.

3.1.2 Hearing Thresholds and Attenuation

Mean hearing thresholds for the unoccluded and protected conditions are shown in Table 1 for each of the nine one-third octave noise bands tested. Results were averaged for the ten subjects. A repeated measures analysis of variance (ANOVA) applied to the data showed significant effects of ear condition, stimulus frequency and ear condition by frequency ($p<0.0001$). In the unoccluded condition hearing thresholds decreased from 30.3 dB SPL to 1.1 dB SPL as the noise band centre frequency increased from 0.125 to 3.15 kHz and then increased to 15.4 dB SPL as the centre frequency increased to 8 kHz. Hearing thresholds were greater in the protected conditions, more so when the orifice in the plug was closed. In the open condition, thresholds were on average 22 dB SPL from 0.5 to 4 kHz, 29 dB dB SPL at 0.25 and 6.3 kHz and 39 dB SPL at 0.125 and 8 kHz. By comparison, in the closed condition, thresholds were on average 28 dB SPL from 0.5 to 3.15 kHz, 23 dB at 4 kHz, 37 dB SPL at 0.25 and 6.3 kHz and 46 dB SPL at 0.125 and 8 kHz.

The mean attenuation provided by the plug in each of the two modes of operation is shown in Table 2. Results were averaged for the 5 males and 5 females. An ANOVA applied to the data with gender as a between subjects factor showed significant effects for mode of operation of the plug, stimulus frequency and mode of operation by frequency ($p<0.01$ or better). In the closed mode of operation the observed attenuation increased as the frequency increased from 14.5 dB at 0.125 kHz to 26.2 dB at 3.15 kHz, decreased to 19.1 dB at 4 kHz and then increased to 31.0 dB at 8 kHz. In the open mode of operation, attenuation increased from 4.4 dB at 0.125 kHz to 21.7 dB at 3.15 kHz, decreased to 16.6 dB at 4 kHz and 6.3 kHz and then increased to 27.0 dB at 8 kHz. The difference due to mode of operation was most apparent at 0.125 kHz and 0.25 kHz, amounting to 9-10 dB. At higher frequencies, the difference ranged from 3-7 dB. While there was no effect of gender either as a main effect or in interaction with mode of operation of the device or stimulus frequency, the attenuation observed for males was generally relatively higher. In the open mode of operation, the difference was 5 dB or less except at 2 and 8 kHz where it reached 8-9 dB. In the closed mode of operation the difference was again less than 5 dB except from 0.125 to 0.5 kHz and 8 kHz where it reached 7-8 dB.

Table 1 Hearing thresholds for the Surefire EP3 Sonic Ear Defender™.

Frequency (kHz)	Unoccluded	Orifice Open	Orifice Closed
0.125	30.3 (5.4)[a]	34.6 (4.8)	44.8 (7.0)
0.25	22.1 (4.9)	28.9 (4.9)	38.1 (5.3)
0.50	11.3 (4.9)	21.l (7.5)	27.6 (6.9)
1.00	7.1 (6.6)	21.4 (6.5)	28.3 (7.0)
2.00	5.8 (2.8)	25.3 (9.3)	30.3 (5.6)
3.15	1.1 (4.3)	22.8 (5.5)	27.2 (3.5)
4.00	3.8 (7.7)	20.4 (7.6)	22.9 (6.1)
6.30	11.5 (4.1)	28.1 (10.3)	35.5 (6.8)
8.00	15.4 (4.2)	42.4 (9.5)	46.3 (8.2)

[a] Mean (SD)

Table 2 Attenuation achieved with the Surefire EP3 Sonic Ear Defender™.

Frequency (kHz)	Orifice Open	Orifice Closed
0.125	4.4 (4.1)[a]	14.5 (9.6)
0.25	6.7 (4.8)	15.9 (7.8)
0.50	9.7 (6.0)	16.3 (8.7)
1.00	14.3 (7.5)	21.2 (10.9)
2.00	19.5 (9.8)	24.5 (7.2)
3.15	21.7 (3.1)	26.2 (2.8)
4.00	16.6 (4.3)	19.1 (5.0)
6.30	16.6 (10.7)	24.0 (7.7)
8.00	27.0 (8.8)	31.0 (8.1)

[a] Mean (SD)

3.2 ATF

The insertion loss results for orifice open and closed modes of operation are shown in Figure 4. The total insertion loss with the orifice open was 45.6 dB SPL, compared to 47.8 dB SPL with the orifice closed. With the orifice open the insertion loss increased steeply from 6 dB at 125 Hz to 38 dB at 4 kHz, and then decreased to 26 dB at 8 kHz. With the orifice closed the insertion loss increased from 24 dB at 125 Hz to 38 dB at 4000 Hz, decreasing to 23 dB at 8 kHz. Differences between the two modes of operation were greatest below 500 Hz.

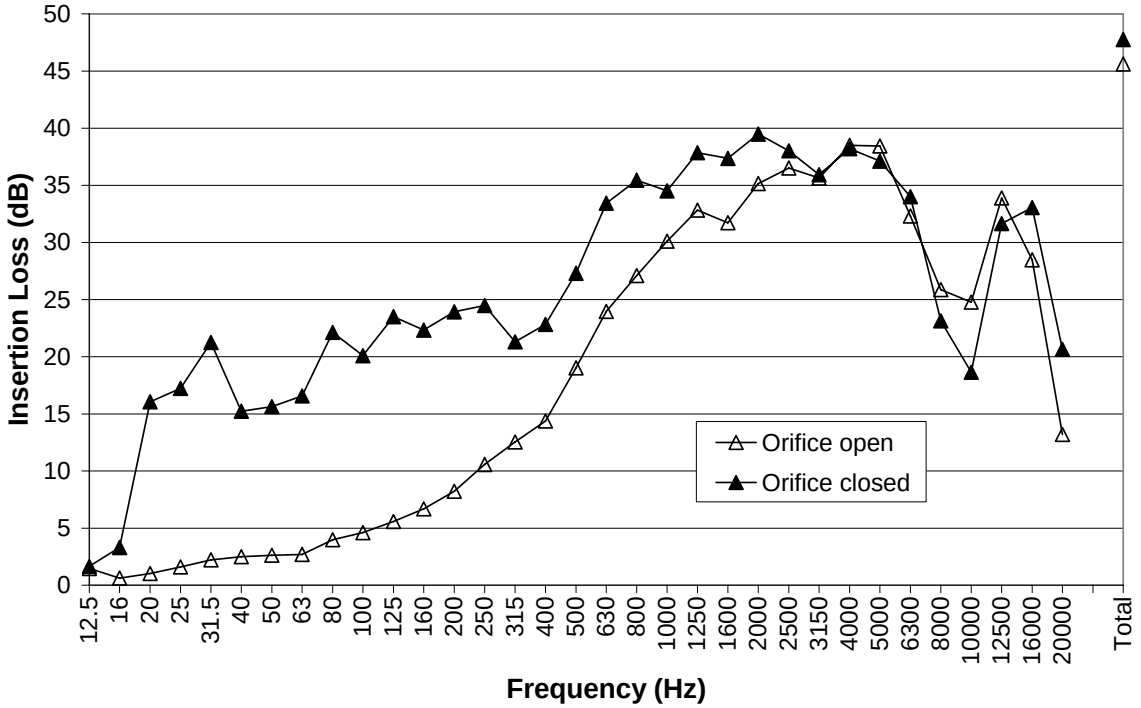

Figure 4 Insertion loss measurements for the Surefire EP3 Sonic Defender™.

4 Discussion

For this study attenuation was defined as a change in human subjects' hearing thresholds [10]. The results showed that the Surefire EP3 Sonic Defender™ performed as a conventional hearing protector when the orifice was closed. The configuration of the function relating attenuation and one-third octave band centre frequency was similar to that observed for other conventional earplugs [1,3]. Across frequencies attenuation ranged from 14.5 to 31.0 dB. A dip to 19.1 dB was observed at 4 kHz, the most susceptible frequency for noise-induced hearing loss [18]. Based on guidelines provided by the Canadian Standard on hearing protection devices [17], the Surefire EP3 would be labelled a Class B device. To attain this class attenuation must range from 5 to 23 dB from 0.125 to 8 kHz. By comparison the E-A-R® Combat Arms plug in the closed mode of operation provided 20.7 to 40.3 dB of attenuation over the same frequency range with 34.3 dB at 4 kHz [4]. The Combat Arms plug would be labelled a Class BL hearing protector. [The L designation indicates that the minimum attenuation achieved is 20 dB (see Figure 5)]. Averaged across the nine frequencies tested, the difference between the devices was 8 dB. At 4 kHz and 6.3 kHz the difference was 15 dB. Standard deviations associated with the mean attenuation for the Surefire EP3 and Combat Arms plugs were on average 7.5 dB and 5.6 dB, respectively. The greater spread in results across individuals wearing the Surefire EP3 may reflect problems with fitting.

With the orifice open the Surefire plug was meant to promote hearing and communication while protecting against exposure to impulsive sounds (e.g., weapon discharge). Observed attenuation in this mode of operation in the absence of an impulse ranged from 4.4 to 27.0 dB. The E-A-R® Combat Arms plug in the open mode of operation provided -0.8 to 24.3 dB of attenuation [4]. The difference between the two devices at 4 kHz was 3.8 dB. Given these outcomes, neither device would be expected to impede speech understanding in either normal-hearing or hearing-impaired listeners. Mean attenuation at the speech frequencies (0.5, 1 and 2 kHz) was 14.5 dB for the Surefire EP3 plug and 13.9 dB for the Combat Arms plug. In individuals with a mild average hearing loss of 35 dB at these frequencies, speech sounds would have to be approximately 50 dB in quiet to be audible (the subject's hearing threshold in quiet plus the sound attenuation), although somewhat higher to be comfortably understood [19, 20].

Insertion loss measurements made with the Surefire EP3 orifice closed fitted to the ATF overestimated the attenuation measurements in human subjects (see Figure 6). With the orifice closed the differences were 8.6 to 19.1 dB in the range of 0.125 to 6.3 kHz. The greatest differences were observed at 1 kHz (13.3 dB), 2 kHz (15 dB) and 4 kHz (19.1 dB). With the orifice open the differences were 1.2 to 21.6 dB from 0.125 kHz to 6.3 kHz. Differences in the range of 1 kHz to 6.3 kHz were similar and on average 16 dB. At 8 kHz insertion loss underestimated attenuation. These differences suggest that the ATF was a poor model of the human peripheral auditory pathway. Previous studies have concluded that the ATF provides a better approximation of the attenuation that can be achieved in human observers when they are fitted with hearing protective ear muffs [13].

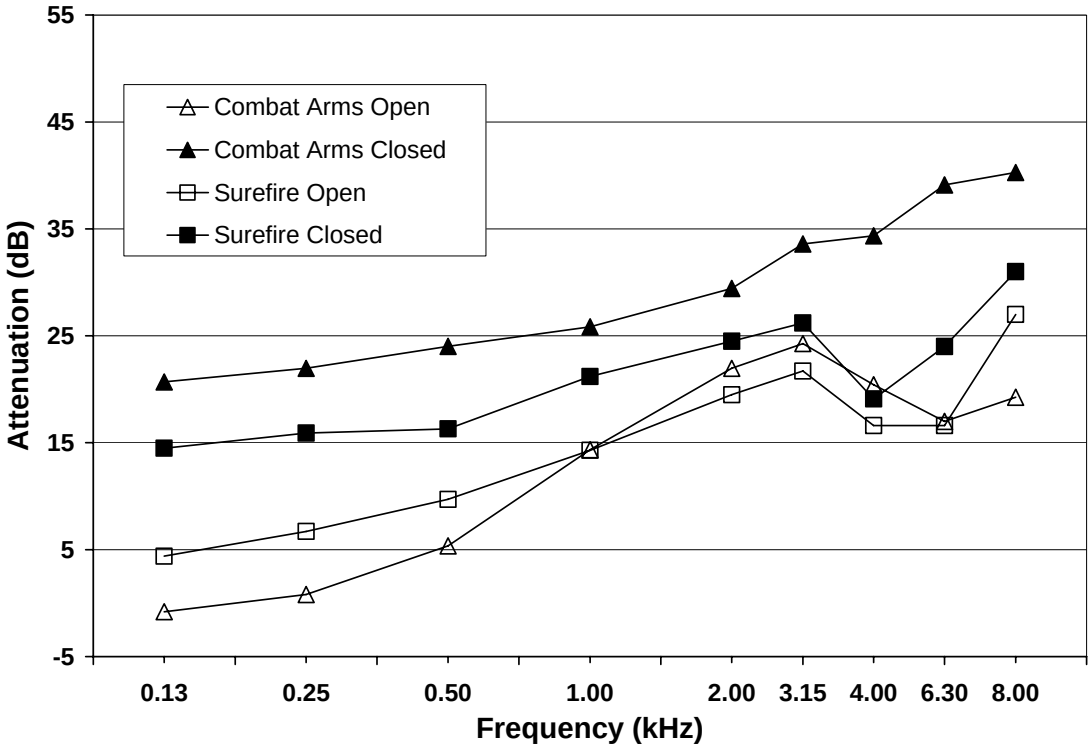

Figure 5 A comparison of results: the Surefire EP3 Sonic Defender™ versus the E-A-R® Combat Arms earplug.

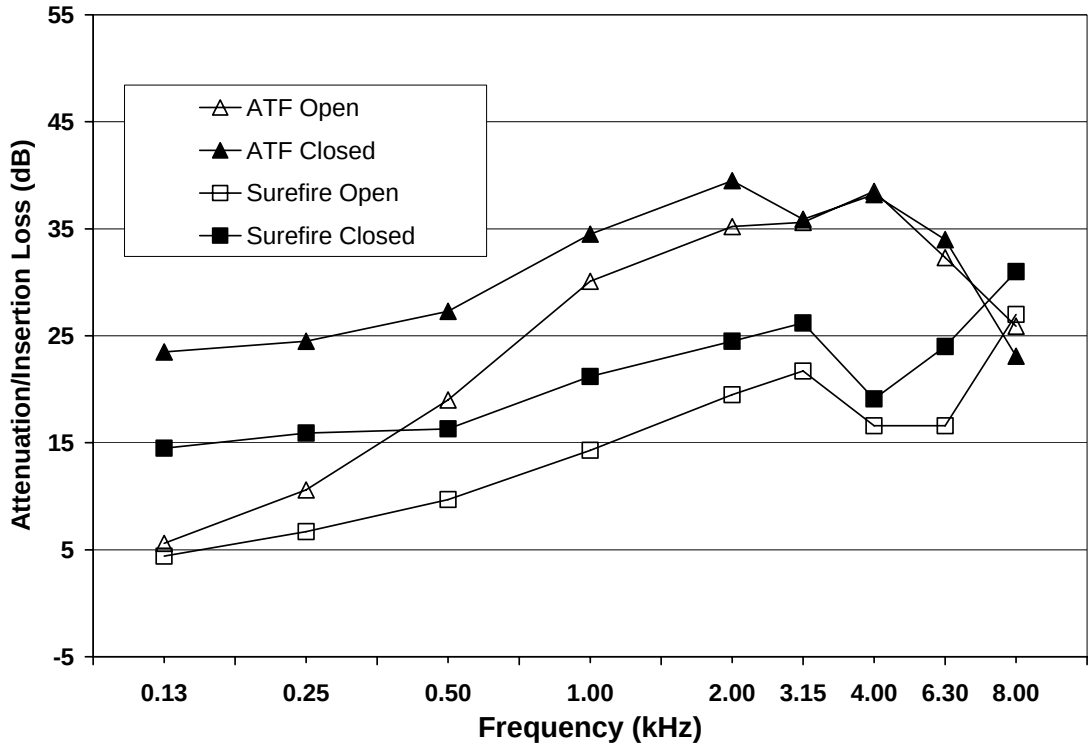

Figure 6 A comparison of results: the Surefire EP3 Sonic Defender™ versus the ATF.

5 Conclusions

1. The Surefire EP3 Sonic Defender™ could be classified as a conventional Class B hearing protective earplug when the orifice was closed. The maximum attenuation achieved was 31 dB. However, the attenuation at the frequency most susceptible to noise-induced hearing loss (4 kHz) was only 19.1 dB. By comparison the E-A-R® Combat Arms plug provided 34.3 dB at 4 kHz.

2. With the orifice open, the EP3 Sonic Defender™ provided at most 27 dB of attenuation. The results were similar to those obtained previously for the E-A-R® Combat Arms plug for the same mode of operation. In the absence of a weapon's discharge either device would be unlikely to impede speech communication in normal-hearing and mildly hearing-impaired individuals.

3. The ATF overestimated the attenuation provided by the Surefire EP3 Sonic Defender™ in both the orifice closed and open modes of operation. The difference was on average 16 dB from 1 kHz to 6.3 kHz.

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List of symbols/abbreviations/acronyms/initialisms

ANOVA	analysis of variance
ANSI	American National Standards Institute
ATF	acoustic test fixture
dB SPL	decibels sound pressure level
HPD	hearing protection device
KEMAR	Knowles Electronics manikin for acoustic research
R&D	research and development

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The sound attenuation provided by the Surefire EP3 Sonic DefenderTM earplug was determined in five males and five females. According to the manufacturer, an orifice in the plug allows safe sound levels to pass while lowering potentially harmful levels above 80 dBA from impulse noise by 35 dB. With the orifice closed the device performs like a conventional level-independent earplug. In each subject, hearing thresholds were measured at nine one-third octave noise band centre frequencies with the ears unoccluded and fitted with the Surefire EP3 with the orifice open and closed. Attenuation was defined as the difference between the protected and occluded thresholds. With the orifice closed attenuation increased non-monotonically from 14.5-31.0 dB from 0.125 kHz to 8 kHz. A decrease to 19.1 dB was evident at 4 kHz. With the orifice open attenuation increased from 4.4-27.0 dB with a decrease to 16.6 dB at 4 kHz and 6.3 kHz. The greatest differences due to mode of operation (9-10 dB) were observed at 0.125 and 0.25 kHz. There was no effect of gender of subjects. Comparison with the E-A-R® Combat Arms earplug, which also has modes of operation for continuous and impulse noise indicated that the two devices were similar for the orifice open condition. For the orifice closed condition the Combat Arms earplug provided attenuation of 20.7-40.3 dB, on average 8 dB more than the Surefire EP3. Surefire EP3 attenuation was also compared with insertion loss measurements obtained using an acoustic test fixture. Insertion loss overestimated attenuation by approximately 16 dB in the range of 1 kHz to 6.3 kHz, regardless of mode of operation.

Nous avons déterminé l'atténuation du son fournie par le bouchon d'oreille EP3 Sonic DefenderMC de Surefire chez cinq hommes et cinq femmes. Selon le fabricant, un orifice percé dans le bouchon permet aux sons dont le niveau est sans danger de passer tout en réduisant de 35 dB les bruits impulsifs dont le niveau est dangereux (plus de 80 dBA). Lorsque l'orifice est fermé, le bouchon se comporte comme un bouchon classique dont l'atténuation ne varie pas selon le niveau sonore. Le seuil d'audibilité de chaque sujet a été mesuré à l'aide de 9 fréquences centrales de bandes de bruits d'un tiers d'octave. Les essais ont été réalisés sans les bouchons et avec les bouchons (orifice ouvert et fermé). L'atténuation se définit comme la différence entre le seuil mesuré avec le dispositif et celui obtenu sans le dispositif. Avec l'orifice fermé, l'atténuation augmente de façon non monotone, entre 0,125 kHz et 8 kHz, de 14,5 à 31 dB. Une diminution à 19,1 dB se manifeste à 4 kHz. Avec l'orifice ouvert, l'atténuation augmente de 4,4 à 27,0 dB avec une diminution à 16,6 dB à 4 kHz et 6,3 kHz. Les différences les plus marquées entre les modes d'utilisation (entre 9 et 10 dB) s'observent à 0,125 et 0,25 kHz. Le sexe des sujets est sans effet. La comparaison avec le bouchon Combat Arms de E-A-R®, qui a lui aussi un mode d'utilisation pour les bruits continus et un autre pour les bruits impulsifs, indique que les deux dispositifs sont similaires lorsqu'utilisés en mode orifice ouvert. Lorsque l'orifice est fermé, le bouchon Combat Arms fournit une atténuation de 20,7 à 40,3 dB, soit 8 dB de plus que l'EP3 de Surefire en moyenne. L'atténuation de l'EP3 a également été comparée avec des mesures de perte d'insertion obtenue à l'aide d'un appareil d'essai acoustique. Cette méthode de mesure surestime l'atténuation par environ 16 dB dans la gamme allant de 1 kHz à 6,3 kHz, peu importe le mode d'utilisation.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS
hearing protection; noice-induced hearing loss

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